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EFFECT OF MODIFIED SEAT ANGLE ON AIR
TO AIR WEAPON SYSTEM PERFORMANCE UNDER
HIGH ACCELERATION

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Aerospace Medical Research Laboratory
Wright-Patterson Air Force Base, Ohio

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<p>In air to air combat, the weapons system that has the highest agility and G maneuvering capability has a decided advantage over a less capable system. A method of increasing the G tolerance of the human portion of the system is the use of reclining seats. However, a question beyond homeostasis is that of performance capability. The modified closed loop Dynamic Environment Simulator system was employed as the experimental test bed for investigation of centrifuge pilots in the reclined position. The centrifuge pilots were required to fly through a series of G on G combat maneuvers and to perform target lock-on and boresight cannon firing through a predictive gunsight reticle at a projected enemy aircraft. The performance scoring was measured as number of ballistic rounds delivered on the target. The seat was constructed with high heel line seat pan angle of 23° and back angles of 30, 45, 55, and 65° measured from G vector vertical. G suit pressures were modified to allow for comfort at more horizontal angles. Results indicate that the greater tilt angles provide for a significant degree of performance enhancement at higher G levels. The data has been developed in the form of a process model of best fit polynomial curves. Correlation of model to scores is .95 or better at each case. For a given performance level; i.e., 50%, there is a 2 G increase in maneuvering capability with a change in seat back angle from 30 to 65°. Also, for a given G level (8 G), there is a performance increase of 30% for the change of seat angle from 30 to 65°.</p>		

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FOREWORD

The research in this report was conducted on the Dynamic Environment Simulator (DES) located in the Environmental Medicine Division, Aerospace Medical Research Laboratory. The program ran over a period of 8 months and involved actual G time exposures that totaled over 50 hours.

Significant contributions to the program were made by the entire DES operating team: J. W. Frazier, V. D. Skowronski, R. U. Whitney, J. A. Brown, MSgt T. G. Shriver, MSgt C. E. Smith, and TSgt D. W. Kelly. The participation of the specially selected subject centrifuge pilots was outstanding. They provided the research group with excellent cooperation and untiring devotion.

The authors wish to express their appreciation to the entire team who made this effort possible.

This technical report has been reviewed and is approved.

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Chief, Environmental Medicine Division
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SECTION I

INTRODUCTION

In air to air combat, the air weapons system that has the highest agility and G maneuvering capability has a decided tactical advantage over a less capable system. In 1954, Gell and Hunter observed and experimented with increased G capability of pilots in the supine position. Other reports of passive centrifugation of human subjects have indicated that a reclining subject is capable of maintaining consciousness at levels exceeding +12 Gx for sustained periods. However, a fundamental question beyond homeostasis is that of pilot performance capability. The pilot, as a functioning part of the weapon system, must maintain some prescribed level of ability to optimize the system in the air to air combat arena. Some questions arising from this need have been investigated on the Dynamic Environment Simulator (DES) at the Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio.

SECTION II

METHODS

The modified closed loop DES system was employed as the experimental test bed for the investigation of tracking performance of centrifuge pilots in the reclined position. Figure 1 shows the DES closed loop air to air control scheme. Here the subject, located in the DES cockpit, is given a HIAD layout of the cockpit with instrumented stick and rudder pedals that represent the control outputs of the pilot. The control outputs are fed to a simulation of the aircraft dynamics that includes the lags and leads of the linkages and control surfaces on the aircraft. These are fed into an airframe dynamic scheme simulation that represents the actual motion of the pilot in the centrifuge's aircraft inflight. From the airframe dynamics, a Gz signal is fed back to the DES controller and then fed to the drive of the DES so that the actual acceleration felt by the man in the centrifuge is that which he creates by his control motions in flying the centrifuge airplane. The airframe dynamics is also fed into a controller that keeps track of a target aircraft and presents display information to the man for his tracking task. At the same time, data is collected in terms of a mission metric on the man's capability to track. The measure of capability is related to the circular error of probability of a ballistic hit with boresight cannon fire on a displayed enemy aircraft.

The seat tilt geometry used for the experiment is shown in figure 2. Here the heel line is held at approximately the seat reference point. Seat pan angle is set at 23° and stationary. The angle back is varied between 30° and 65° ; all angles measured from the vertical. The display on which the man's tracking information is present is rotated back with the seat so that the display gains remain constant throughout the experiment. The angle indicated in both figure 2 and following, when translated to the aircraft, would be a composite of both the seat angle plus the angle of attack of the aircraft. Thus, the effective seat angle is actually the seat angle plus the angle of attack of the aircraft so that a 30° seat shown here would correspond with a 17° angle of attack during a particular movement in the aircraft plus a 13° seat back angle. The G valve fill schedule is shown in figure 3. Here the steeper back angles; that is, 30° , 45° , 55° , and 65° , were given lower fill pressures for a given G force. This was to provide for pilot comfort at the steeper back angles. Because the tilt back position provides a degree of protection in itself, it was not necessary to provide standard fill pressure schedule on the G-suit at these angles.

The sequential mission profiles are shown in figure 4. The subject pilot is placed in a constant $1\frac{1}{2}$ G turn as a baseline maneuver. The baseline turn is followed by rapid onset peaks forced by the movement of the target aircraft to levels of G between 4 and 8. The G peak is followed by a firing period at 3 G and then a return to the baseline level. The baseline peak and firing level are set at approximately 30 seconds. There are 12 peaks in each daily mission profile, amounting to approximately 30 minutes of run time for each centrifuge pilot. For the cases shown in figure 4, there are three separate time epochs consisting of four G levels that

are repeated through the first, second, and third epoch. Within each time epoch, the G levels at peak are randomized. Figure 5 provides a breakdown of each particular peak G period and shows the scoring periods used in the test. Each particular G peak test lasts approximately 110 seconds. The pre-G period or baseline period counted from 0 through 30 seconds provides the baseline scoring data on which to compare the during-G period from 40 through 70 seconds and the post-G firing period from 80 through 110 seconds. Ten second delays are provided between each of the levels to allow time for washout of any effects in the acceleration transients required for the changes in G levels.

The gunsight represented in figure 6 provides the primary visual cues for the air to air tracking task. The sight and target are computer generated and electronically displayed to the subject with appropriate scaling for dynamic fidelity. The sight is located in a standard position and rotated back with the seat. The sight display provides a simulation of lead angle computation as is necessary for accurate performance measurement. Certain assumptions are made to simplify the simulation and the analysis. The assumptions are that the corrective angles in aligning the sight are small and they are a function of G force, range, and the velocity of the round. The sight display is depicted in figure 6. Here (a) is the roll angle, (dx) represents yaw displacement, and (dz) represents the pitch displacement from target alignment. Both dx and dz include prediction offsets. In the figure, the chase plane is in a right hand roll. The dz displacement represents the difference between the acceleration of the target aircraft and the chase aircraft. When both are partly aligned for a specified period of time which corresponds with the lead computation time to indicate a good sighting, then the subject is given a hit score in terms of the round rate and circular error of probability for the target sight alignment. Thus, for the centrifuge pilot to score a hit, he must fly the centrifuge at the same G levels and use the same maneuvers that the target aircraft is required to fly.

SECTION III

RESULTS

At the end of each run, the subjects are polled with a questionnaire designed to look at a number of factors, all of which relate to the subject preference for the seat. Included in this survey is a technique for extracting a rating score for a particular seat angle after certain levels of G are achieved by the pilot subjects. Figure 7 is a demonstration of the results of the subjective rating of the tilt back seats at 13 through 65 degrees after the subjects had concluded the portion of the experiment that covered the range from 4 to 7 G. The preferred seat angle after this series of runs was 45° with a strong preference toward 55°. However, as is demonstrated in figure 8, the subjects, after riding to 8 G in the various angles except 13°, had their preference shift toward the steeper angles and that the preferred seat angle at 8 G was now 65° rather than 45°. The tiring effects for the sequential mission profiles are shown in figure 9. The hit score averages for all seat angles through the three time epochs are also shown. There is no significant difference from epoch 1 to epoch 2 to epoch 3 in terms of a decay in hit score over the 30 minute time period the pilots were required to fly the mission profiles. Figure 10 is a representation of the performance summary for the entire high acceleration (HAC) program showing the results during the G pulse; scores are shown in terms of percent hit score. The bargraph demonstrates the decay with increasing G and also demonstrates the performance gain with increasing seat back angle. Also noted here is that the effect of the seat back angle below 6 G showed no statistically significant difference in the performance scores. Figure 13 shows a process model by means of a best fit polynomial for the percent hit score change with G levels with the parameters of 30, 45, and 65° seat back angle. The 55° seat back angle is not shown here because it closely coincides with 45° information indicating that there may be a nonlinearity in the performance capability in the change from 30 to 65°. That is, there may be an increase from 30 to 45°, very little increase from 45 to 55°, and then an increase again from 55 to 65°. The best fit polynomials as shown with a 30, 45, and 65° parameters obtained during the 30 second G pulse. The correlation of scores to the process models as shown in the polynomial curves are better than .99 in each case. The performance curves for the post-G period (figure 14) show a grouping of the 30 and 45° angle performance and a grouping of 55 and 65° performance. The spread between 45 and 55° indicates a possibility that the seat angle adjustment during G may be a critical factor in the post-G recovery phase. The spread in the post-G performance curves in the high G ranges is more sensitive to the seat angle than the during-G performance would indicate. Figure 13 is a demonstration of the Δ G obtainable through the seat back angle change. For a given performance level, such as 50%, the change from 30° seat back angle to 65° seat back angle provides a Δ G increase in capability of nearly 2 G. Figure 14 demonstrates the Δ performance gain through a change from 30 to 65° at a given G level. In the example, at 8 G a change from 30 to 65° provides a Δ performance of nearly 30% increase in capability.

In conjunction with performance measurements obtained during the period of this experiment, some physiologic measures were also taken to provide a secondary descriptor of

the state of the man during the experimental stress. One of the parameters measured was the heart rate of the centrifuge pilot subject. Equation 1 is a predictive heart rate equation that represents baseline heart rate and a component of heart rate which is due to the G vector where the vector is broken into both a cosine function and the sine function. A_0 represents the baseline rate, A_1 is the coefficient of cosine term, and A_2 is the coefficient of the sine term. G_t is the total G apparent at the cab, X_s represents the seat angle from vertical or the seat angle from the G total. In this system, if we let an angle, X_p , which is the physiologic angle be equal to the seat angle minus an offset angle y , as shown in equation 2, then there might be a y such that the heart rate is equal to a baseline rate A_0 as before plus some coefficient times the total G multiplied by the cosine of the physiologic angle, X_p . From the data derived from the experiment, the y is found to be the effective physiological angle or y equals $7\frac{1}{2}^\circ$. The significance of this is seen because the angle from the aorta to the carotid sinus is approximately $7\frac{1}{2}^\circ$; thus, it is a demonstration of the cardiovascular control axis at $7\frac{1}{2}^\circ$ which plays the important role in the tilt back seat. Figure 15 is a correlation between the heart rate in beats per minute and hit scores. Figure 16 is a demonstration of the effects of the seat back angle given in parametric form as opposed to heart rate and total acceleration force. For a given acceleration force such as 8 G with a variation from 30 to 65° that there is a heart rate shift from 123 to 165. A lowering of heart rate by an increase in seat back angle is readily apparent.

PREDICTIVE HEART RATE EQUATIONS

$$H=A_0+A_1G_T\cos(X_5)+A_2G_T\sin(X_5) \quad (\text{EQ 1})$$

$$\text{LET } X_P=X_S-Y$$

THEN THERE IS A Y SUCH THAT

$$H=A_0+A_3G_T\cos(X_P) \quad (\text{EQ 2})$$

Y IS THE EFFECTIVE PHYSIOLOGIC ANGLE

$$Y=7.5 \text{ (DEGREES)}$$

SECTION IV

DISCUSSION

The effects of the tilt back seat seem to be that of increased performance in the centrifuge pilot's capability to perform the air to air gunnery task with an increase in the seat angle from vertical. The problem of vision remains to be resolved; however, the man's capability to perform as a controller and as a pursuit tracker in the air combat arena undergoing excessive G for sustained periods of time seems to indicate that the tilt back seat is a necessary adjunct to future high agility aircraft. The significant benefits of the tilt back seat increase with higher G and provide for a greater subject acceptance. Physiologically, the steeper seat angles from vertical have the effect of lowering heart rate, a factor that may be significant in terms of cardiac workload. However, this concept must be explored with more definitive techniques to gain an understanding of the changes in physiology with the steeper angles.

The effectiveness of tilt back seat becomes more significant at the higher G levels and, in view of the necessary protection that must be afforded the human, may be extremely necessary for the higher G loadings in sustained air combat maneuvering. The subject acceptance of the steeper angle seats is high, and the preference for the steeper angles at the higher G loads is noted previously. Again, the effectiveness of the repetitive G is shown to have little or no effect in terms of performance decay over sustained periods of time. A predictive heart rate model is defined that allows for parametric estimation of heart rate for various seat angles and vehicles. From this model, the cardiovascular control axis is called out and is an indicator that the head angle can be increased over the back angle for an allowance of increased head height with little or no effect on performance or heart rate. The series of tests as reported open the door for a follow-on program in the study of both performance and physiology with the tilt back seat in the higher sustained G region. An optimization of the seat angle in terms of aircraft structural facility and vision and performance payoff is necessary and optimization of suit pressure schedule in timing fill pressure and pressure schedule is necessary. A study of the optimization of physiology in terms of heart rate, cardiac output, and cardiac work should be pursued to optimize the physiology of the man against the suit pressure against the protective mechanism of the tilt angle and against the tradeoff variables in terms of vision and performance within the aircraft.

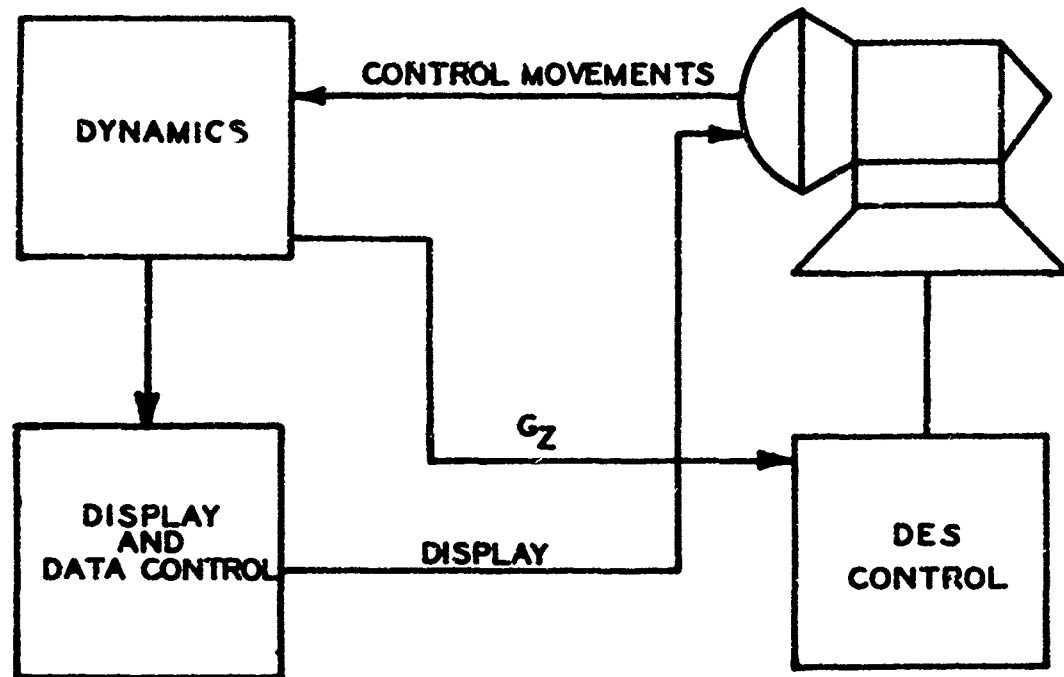


Figure 1 DES Closed Loop Control Diagram

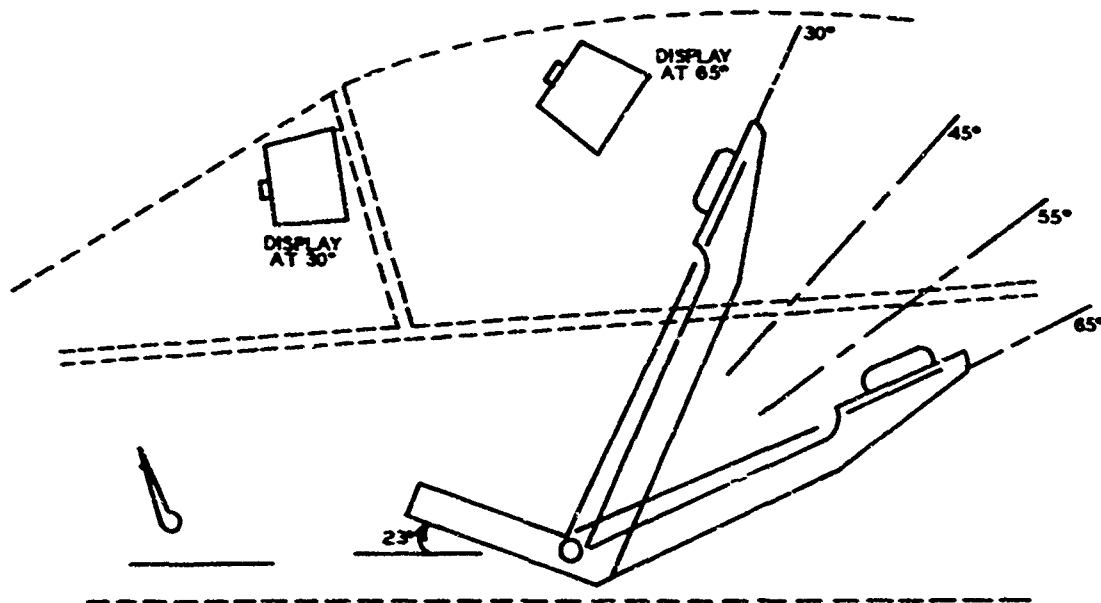


Figure 2 High Acceleration (HAC) Seat Tilt Geometry

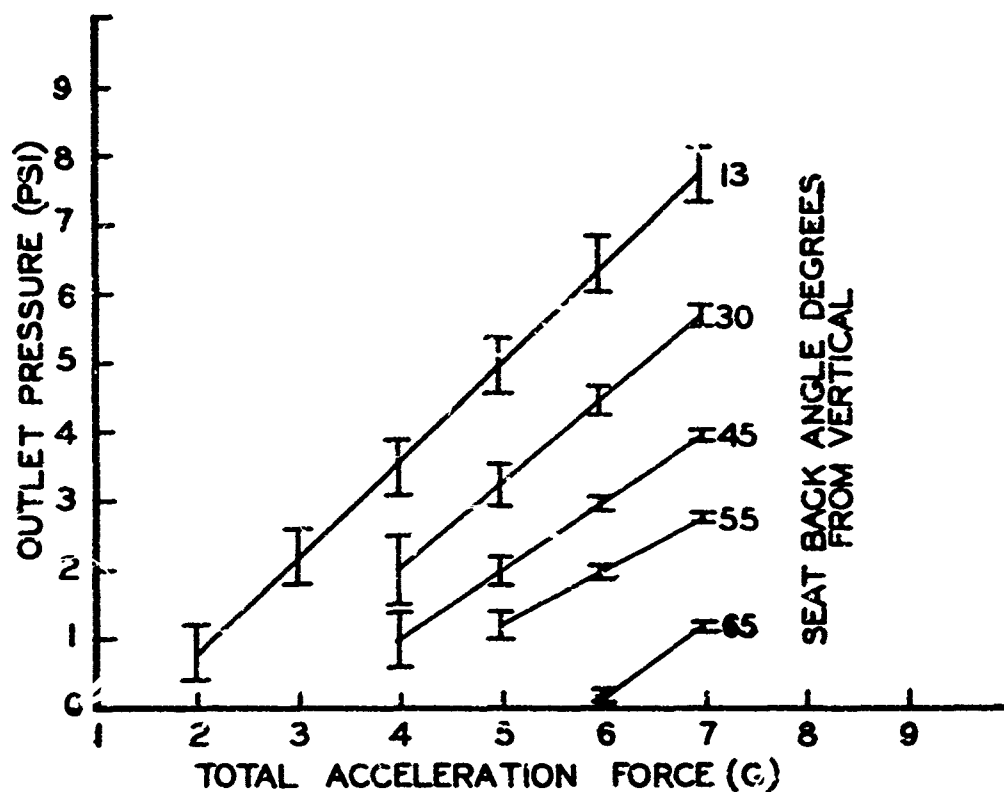


Figure 3 Suit Pressure Schedule

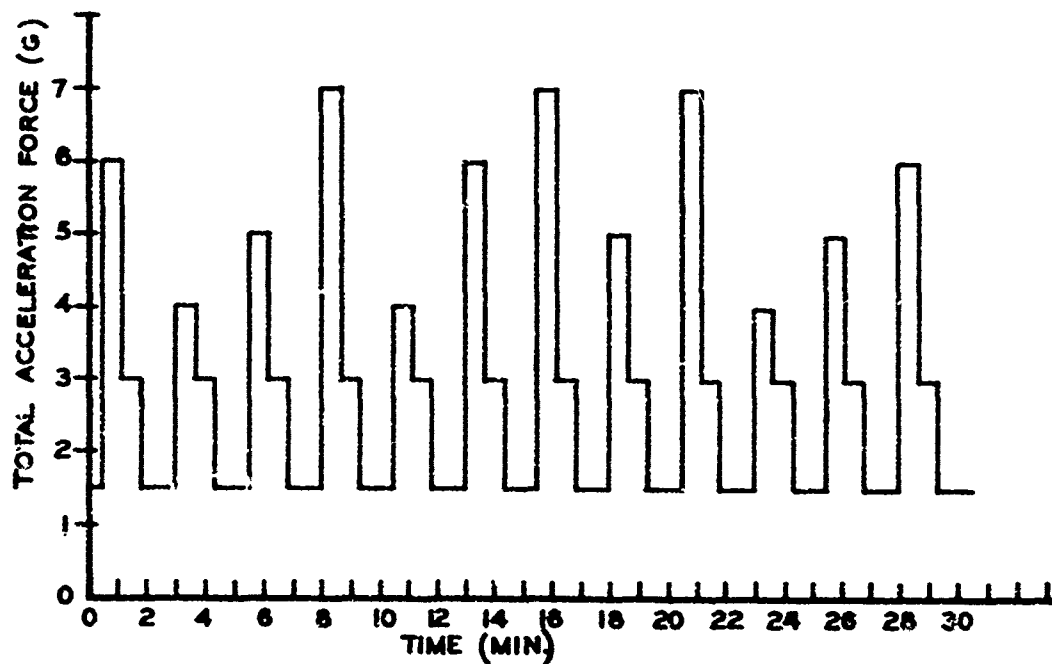


Figure 4 Sequential Mission Profiles

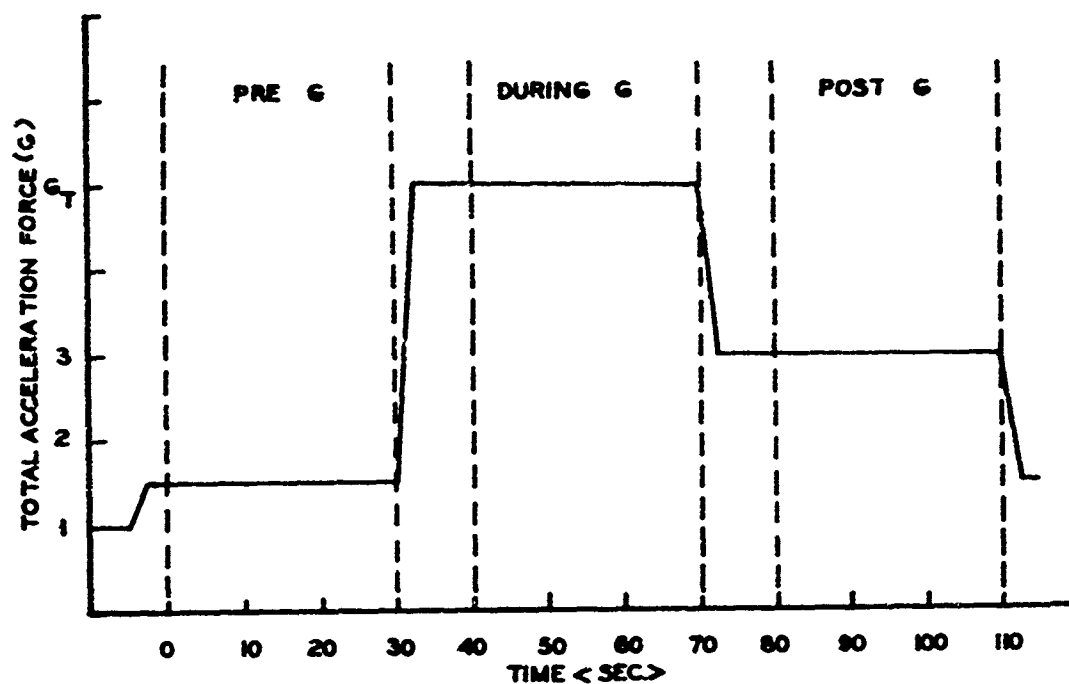


Figure 5 Time History of G Exposure

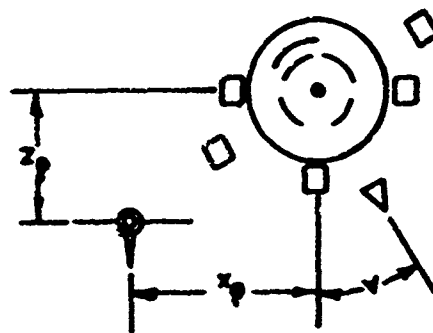


Figure 6 Heads Up Sight Display

A is roll angle, dx represents yaw displacement and dz represents pitch displacement from target alignment. Both dx and dz include prediction offsets. Chase plane is in right roll.

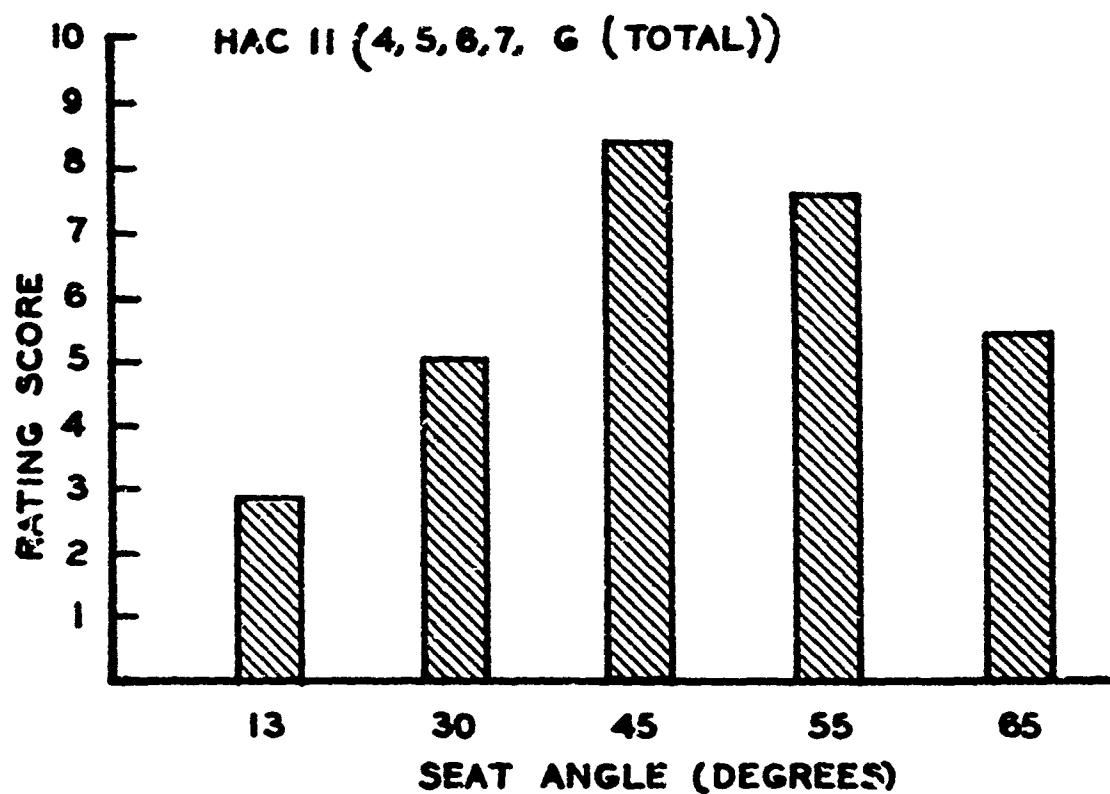


Figure 7 Subjective Seat Rating, HAC II

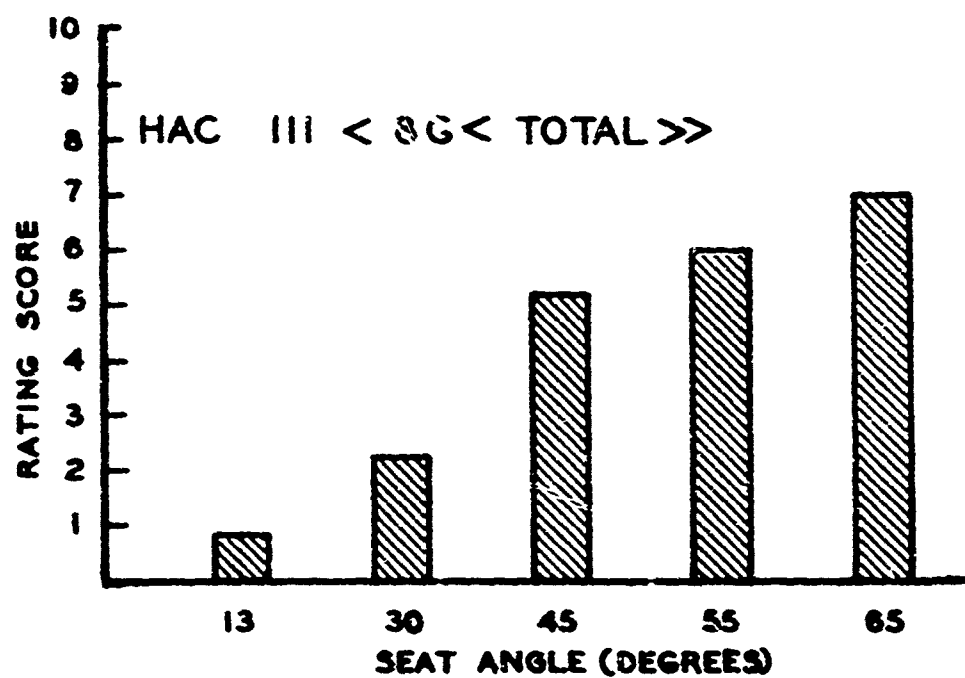


Figure 8 Subjective Seat Rating, HAC III

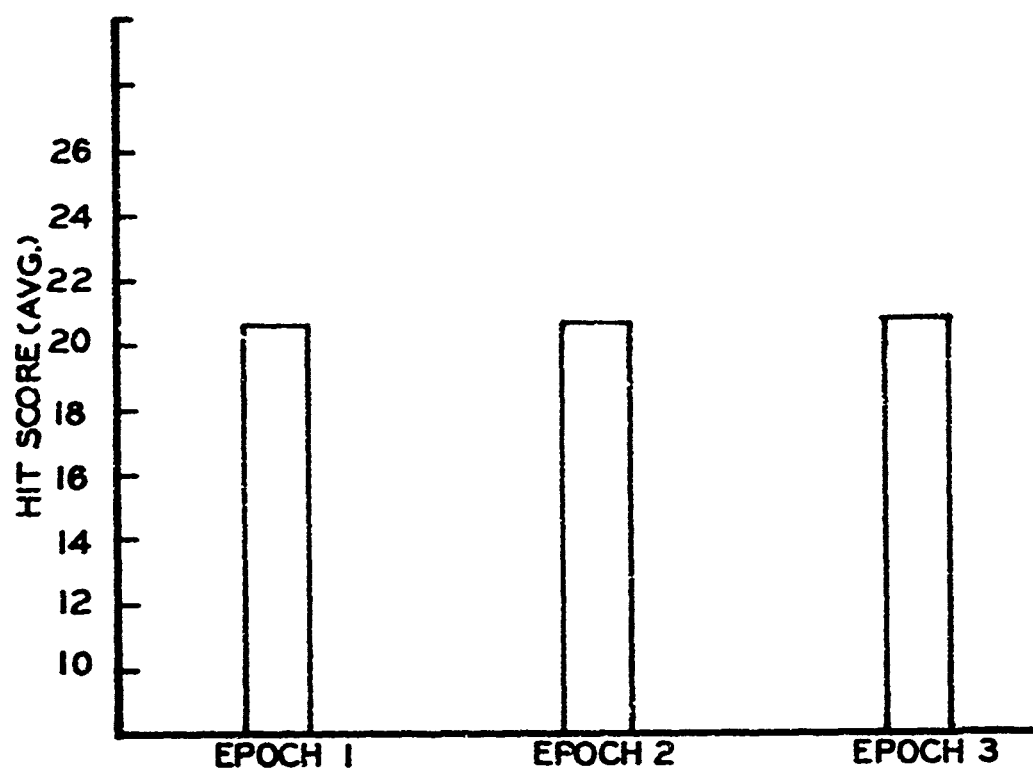


Figure 9 Results for Sequential Mission Profiles

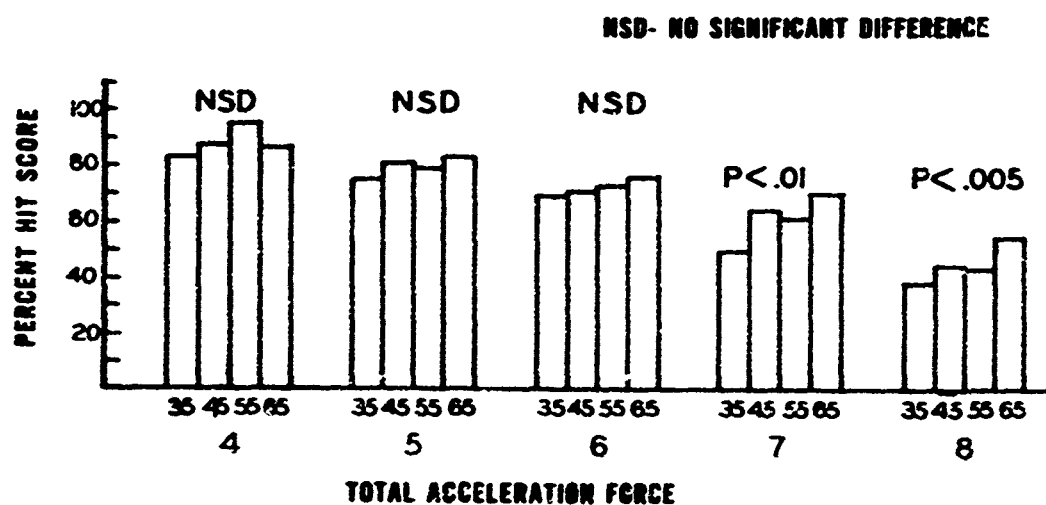


Figure 10 Performance Summary—HAC II-III During G Pulse

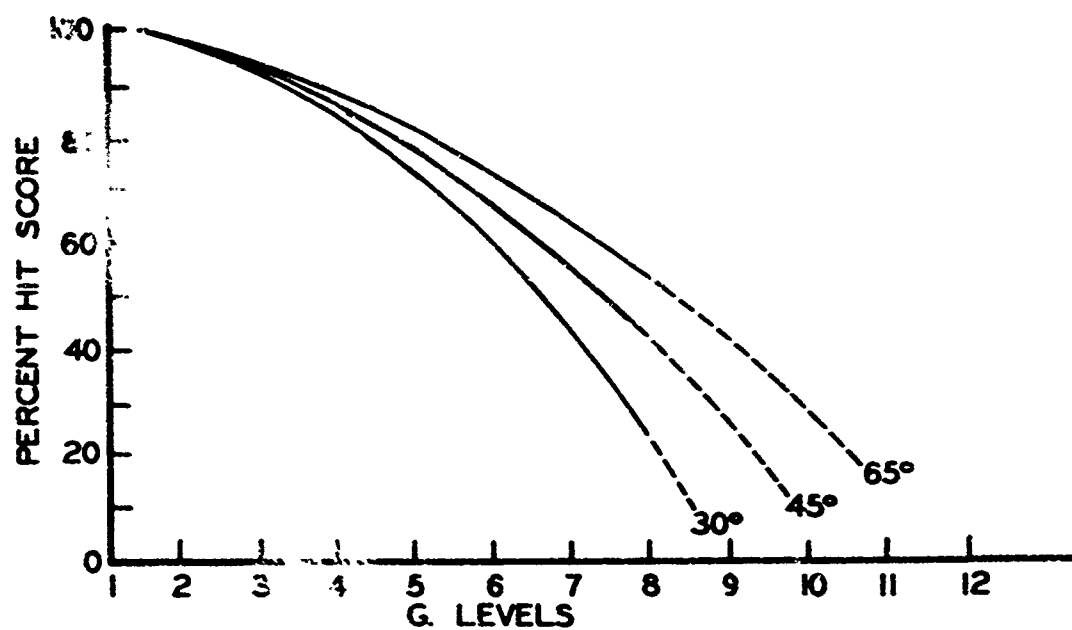


Figure 11 Best Fit Polynomials by Seat Angle During G (30 Sec G Pulse)

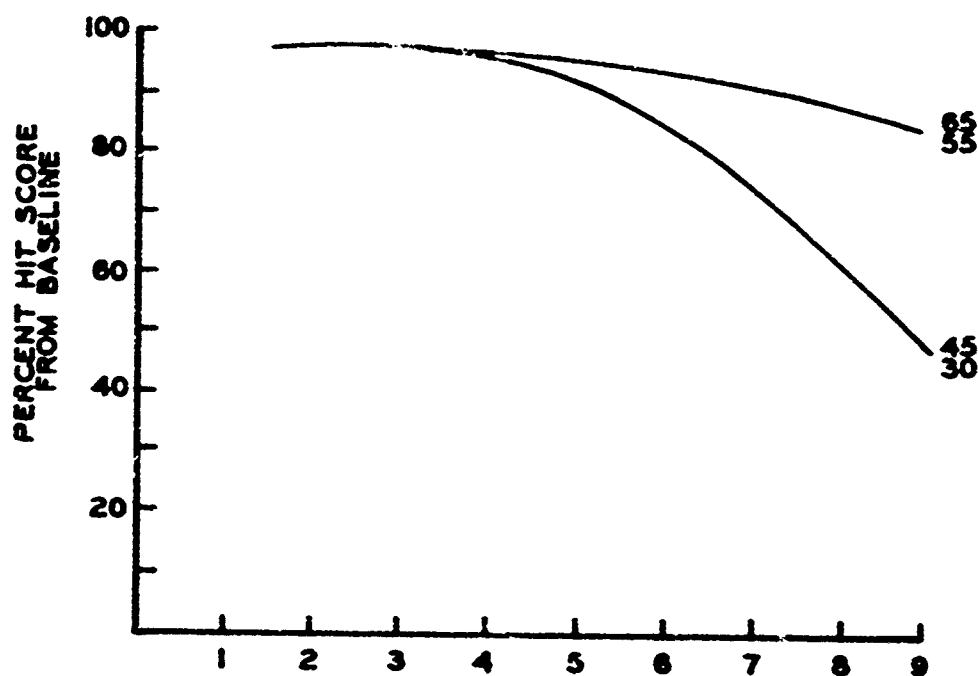


Figure 12 Best Fit Polynomials for HAC Angles Post G Period (3G 30 Sec)

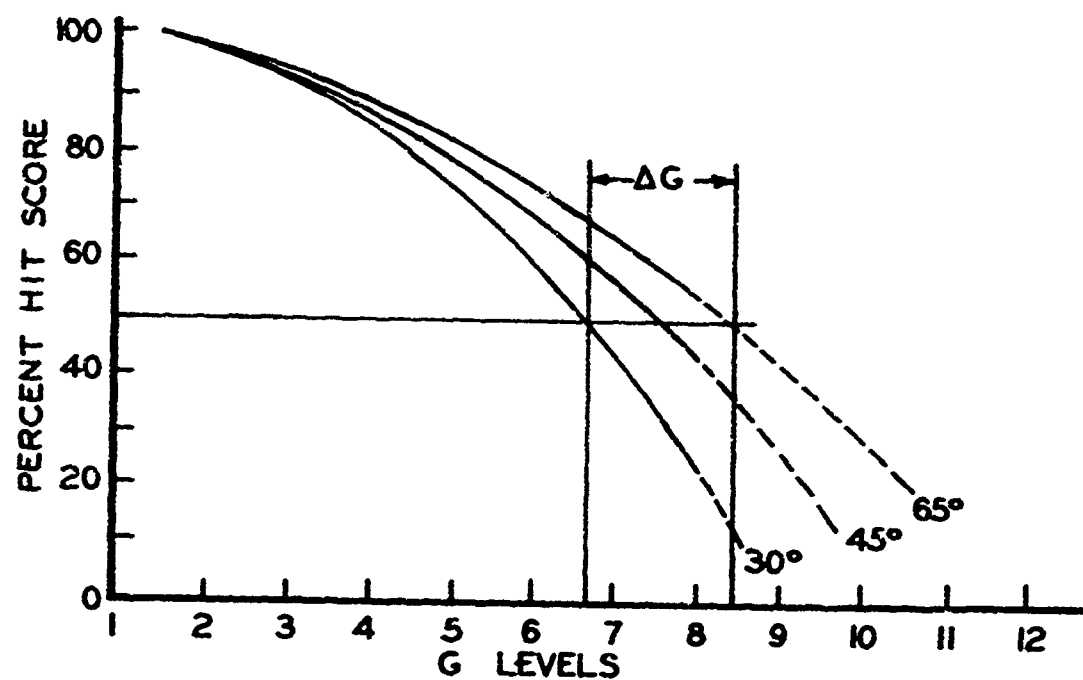


Figure 13 Best Fit Polynomials by Seat Angle During G (30 Sec G Pulse
G Indicates a Given Performance Level

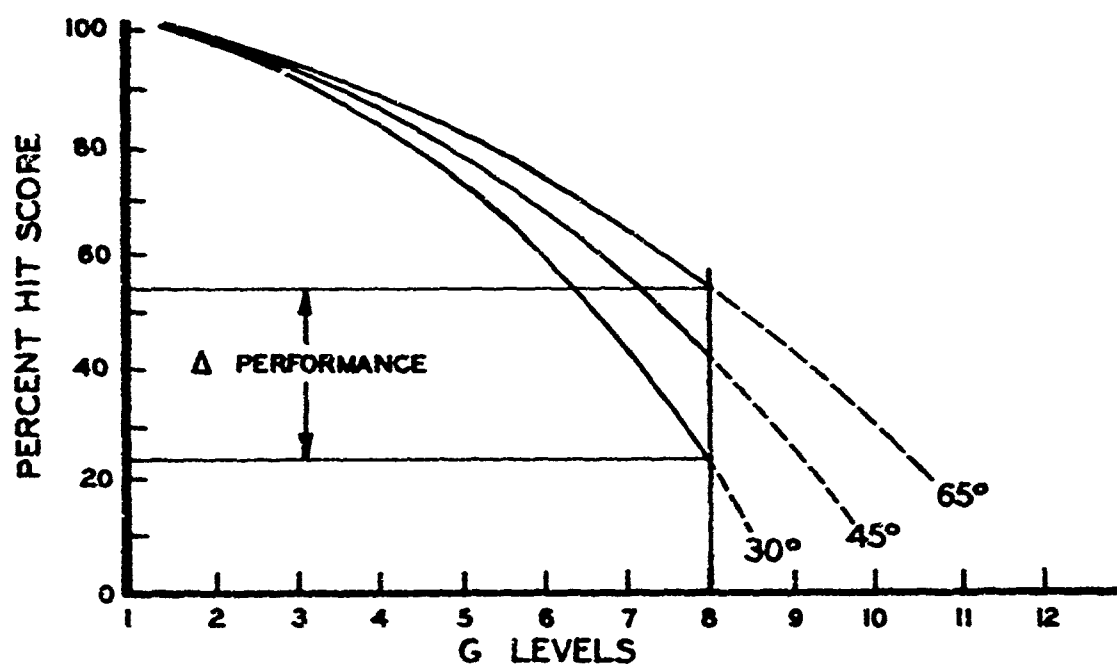
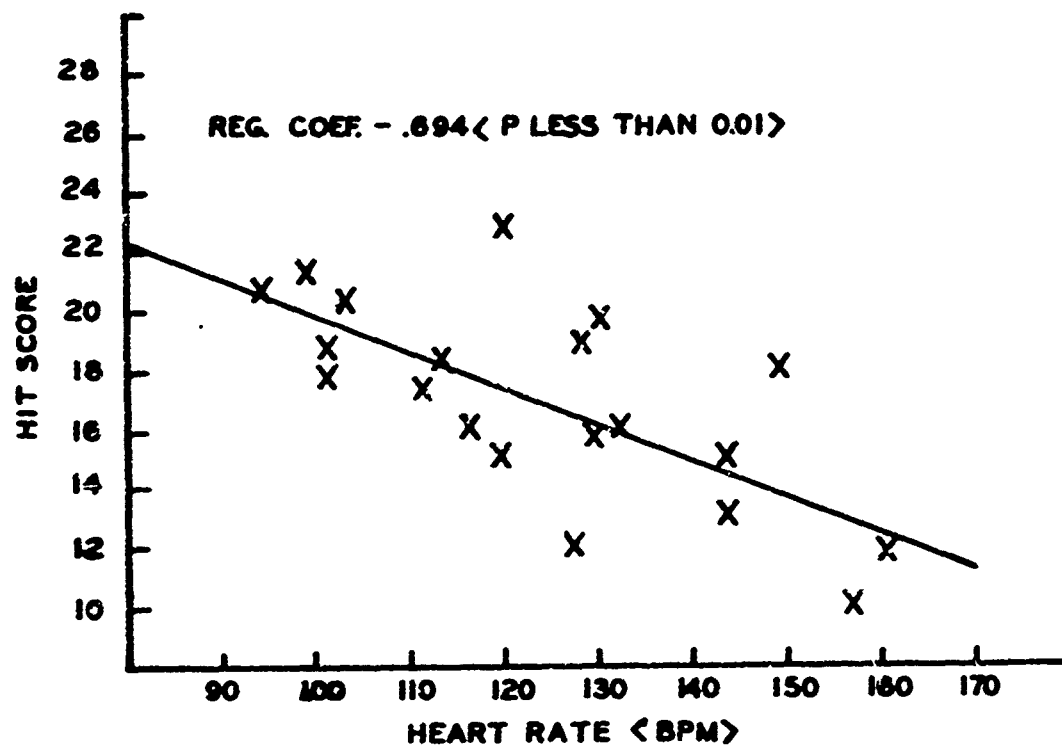


Figure 14 Best Fit Polynomials by Seat Angle During G (30 Sec G Pulse)



Showing Performance for a Given G Level
 Figure 15 Regression Curve for Corrected Heart Rate and Hit Scores

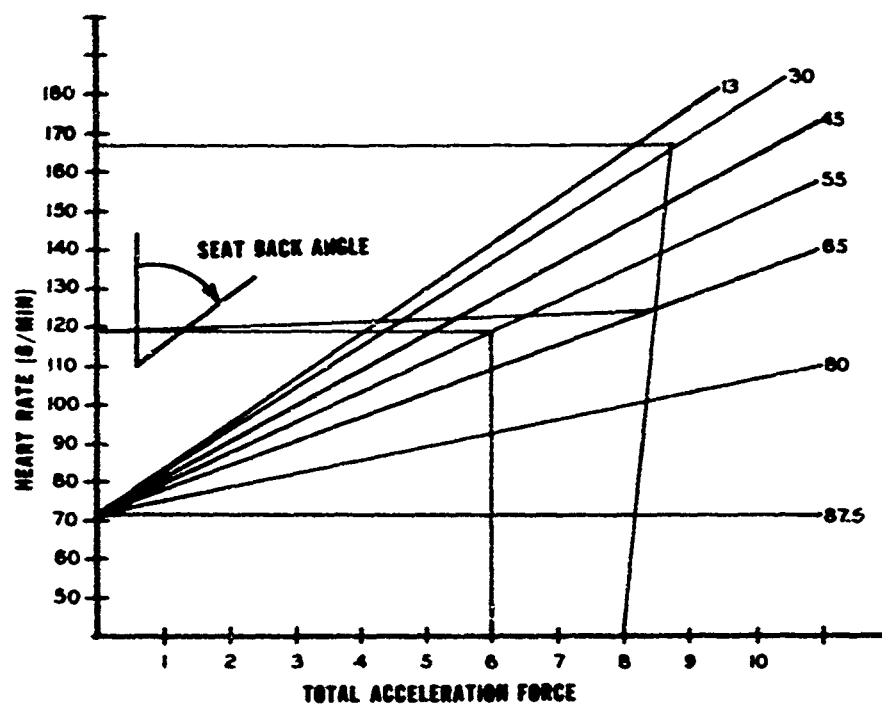


Figure 16 Predictive Heart Rate Curves